Shear-wave Velocity of the Post-Paleozoic Sediments in the Upper Mississippi Embayment : Collaborative Research between the University of Kentucky and the University of Memphis

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Element : I

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Investigations Undertaken :

During the current USGS project support that started on March 1, 2002, the UK and UoM team have conducted seismic reflection and refraction profiles adjacent to two CERI seismic network stations, a few deep well-sites, and a few sites of shallow sediments in the upper Mississippi Embayment (Figure 1). Short seismic reflection and refraction profiles using P- and SH-wave sources were conducted at these sites. The P-wave source was powerful enough to observe strong reflection from the bottom of the sediments even at the southern most sites where the thickness of sediments is around 800 meters. However, the S-wave hammer source was used to sample only the uppermost ~100 meters of sediments. The experiment was designed to demonstrate that P-wave velocity model for the sediments beneath a seismic station can be determined from the analysis of traditional seismic reflection and refraction profiles. Nearby deep wells with geological and sonic logs can provide critical information to constrain the interpretation and to validate the results from the P-wave profile. Therefore, a well-defined P-wave velocity profile for the entire sediment section and shallow S-wave velocity profile beneath each site have been determined. In the remaining period of the current project, we will try to use a more powerful MiniVib source which can be used either as a P- or a S-wave source to sample the entire thickness of sediments in the embayment.

We also inspected all seismograms since 1995 at the CERI stations near each site of seismic profile. The arrival time differences Δt_{S-S_p} between the direct S and the S-P converted waves (Sp) from the bottom of the sediments are measured from each seismogram. Since the velocity contrast between the bottom of sediments (Vp≈2.2 km/sec) and the underling Paleozoic rocks (Vp≈6.0 km/sec) is extremely high, the direct S and the converted Sp waves are likely to incident to surface stations near vertically in spite of epicentral distances, depths, and azimuths of earthquakes. Therefore, the arrival time differences Δt_{S-S_p} observed at each site from earthquakes of various depths, azimuths, and epicentral distances are almost a constant which can be determined from a simple least square fitting. The S-wave velocity model for deeper sediments can thus be preliminarily determined from a simple linear inversion of Vp/Vs ratio for the sediments using Vp model, shallow Vs model, and Δt_{S-S_p} as the *priori* information.

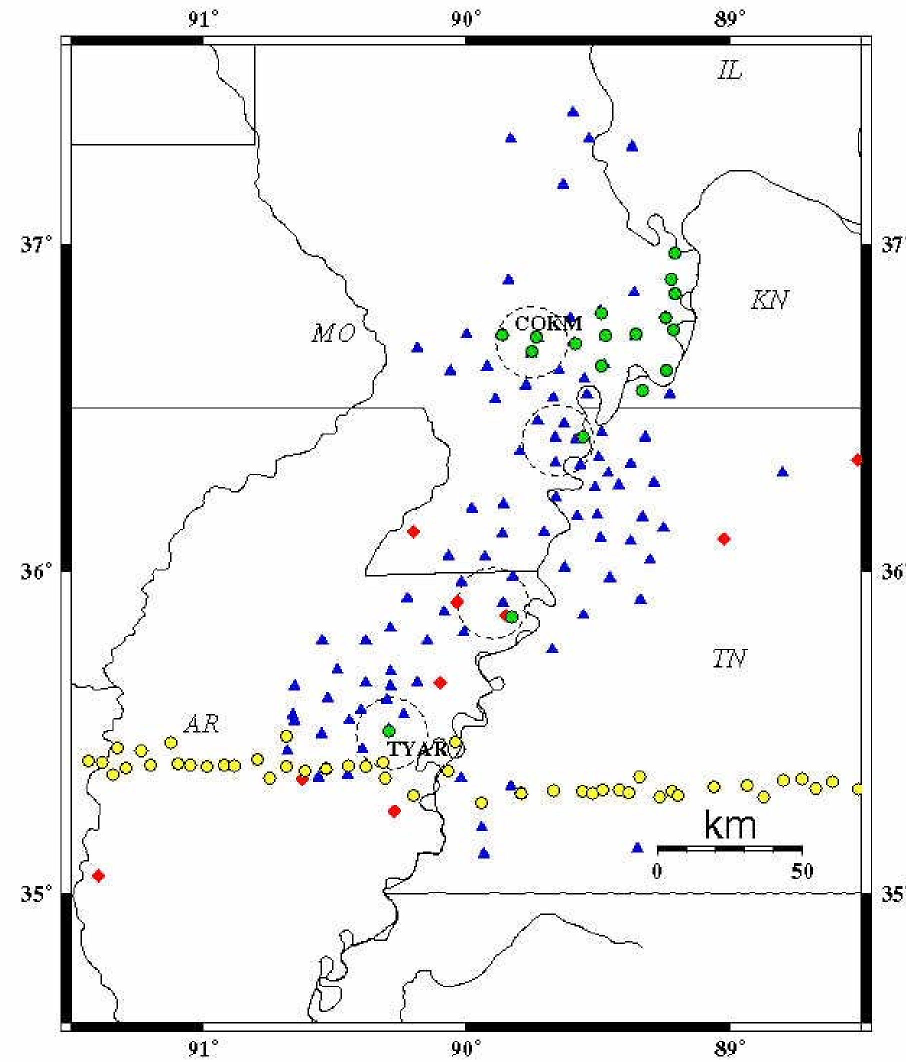

Figure 1. Map showing CERI seismic station locations (solid blue triangles) and deep wells/well-logs (solid orange diamonds). Open yellow circles along an east-west orientation are the locations where seismic profiles are available at the University of Kentucky from previous experiments. Dashed large circles around TYAR, COKM, and two other deep well sites are the clusters of sites done during the current project. Additional P- and S-wave seismic profiles are also collected at northern upper Mississippi embayment near Kentucky, Tennessee, and Missouri border (solid green circles) where thickness of sediments is relatively thin (200~300 meters).

Results

Figures 2a and 2b show the representative P- and SH-wave seismic profiles, respectively, that are being collected and processed. Strong layered interface inside the sediments can be clearly identified. Comparisons of these seismic data with nearby well log data (Figure 3) often found agreement of major horizons within 5%; however, in a few instances mists of a little more than 10% was observed. A powerful MiniVib source to be used in the future will significantly enhance the strength of seismic signals to improve the resolution and accuracy. Because velocity contrast across the bottom of the sediments is the strongest among all the sedimentary interfaces, and P-wave sources have the capacity to sample the entire section of sediments, clear reflections from deep interfaces including the top of the Paleozoic bedrock can be identified and analyzed (Figure 2a).

The S-wave hammer source was used to sample the very near surface interfaces shallower than ~100 meters (Figure 2b). In the remaining period of the current project, we are planning to use MiniVib S-wave source to improve the sampling depth of the S-wave. Figure 4 shows a summary of the interpreted shallow S-wave velocity profile for a few selected sites in the upper Mississippi Embayment. The shallow S-wave velocity models show very significant lateral variations and very slow S-wave velocity near the surface, most probably due to the existence of water in the shallow sediments. Depths of the top three interfaces are somewhat consistent but the difference of interval S-wave velocity between different sites increases at deeper depths.

Figure 5 shows two interpreted Vp profiles beneath the TYAR station near Marked Tree, Arkansas where abundant converted waves are observed from local NMSZ earthquakes. The two Vp profiles include one from the interpretation of seismic profile (red line) and the other from interpolation of the nearby deep well-logs (blue line). It is apparent that the interval P-wave velocity and major interfaces inside the sediments from the two P-wave profiles are very consistent with minor differences which indicates that a reliable P-wave model for the sediments is possible from seismic reflection and refraction profiles.

Figure 6 shows a typical 3-component seismogram recorded at one of the CERI seismic station. Clear S and P-to-S converted wave arrivals can be identified from the two horizontal components (top two traces). The P and S-to-P converted waves can be easily identified on the vertical component (bottom trace). The arrival time difference between the direct and the converted waves (Δt_{S-S_p}) for each site is a constant from earthquakes of various epicentral distances and azimuths which varies, however, between different sites (Figure 7). Since Δt_{S-S_p} is proportional to the thickness of sediments beneath each site, a simple 1-D linear inversion of Vp/Vs ratio can be achieved to determine the S-wave velocity model for the deeper sediments using the P-wave model, the shallow S-wave model, and the Δt_{S-S_p} observations as the *priori* information. The resultant S-wave velocity model for the selected site is shown in Figure 5 (green line) which satisfies the observed Δt_{S-S_p} and other relevant information at this site. In the future experiment using MiniVib S-wave source, we should be able to determine the S-wave velocity model for the entire thickness of sediments from the seismic profile. Results of S-wave model obtained from the 1-D linear Vp/Vs inversion should be supplemental to that determined from the seismic profiles.

Since the sedimentary basin in the upper Mississippi Embayment is characterized by very significant vertical and lateral velocity structural variations, a systematic research similar to the one presented here over many sites in the area is the only effective and reliable approach to achieve a realistic 3-dimensional model of the sedimentary basin.

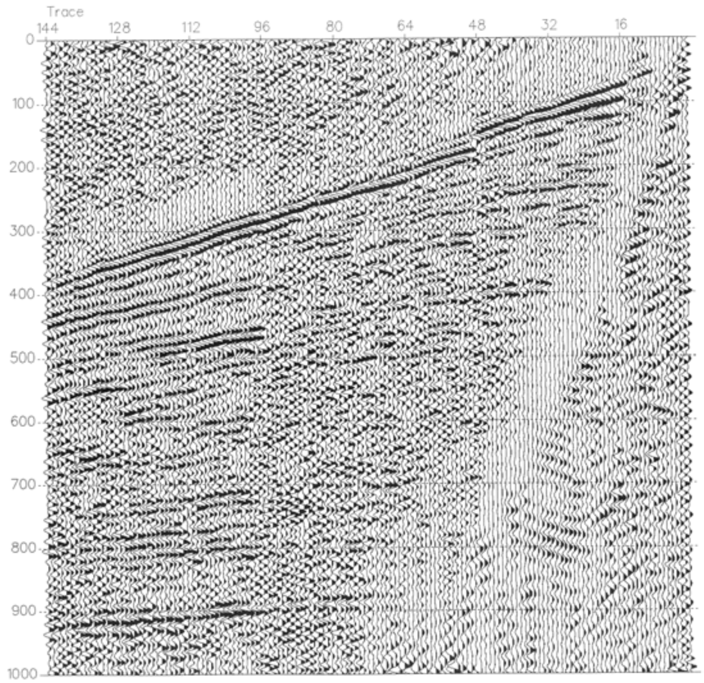

Figure 2a. Example of a processed P-wave sounding near station TYAR. Time, in milliseconds, is represented on the vertical axis. The trace spacing is 4 meters. The bedrock intercept is at approximately 860 ms.

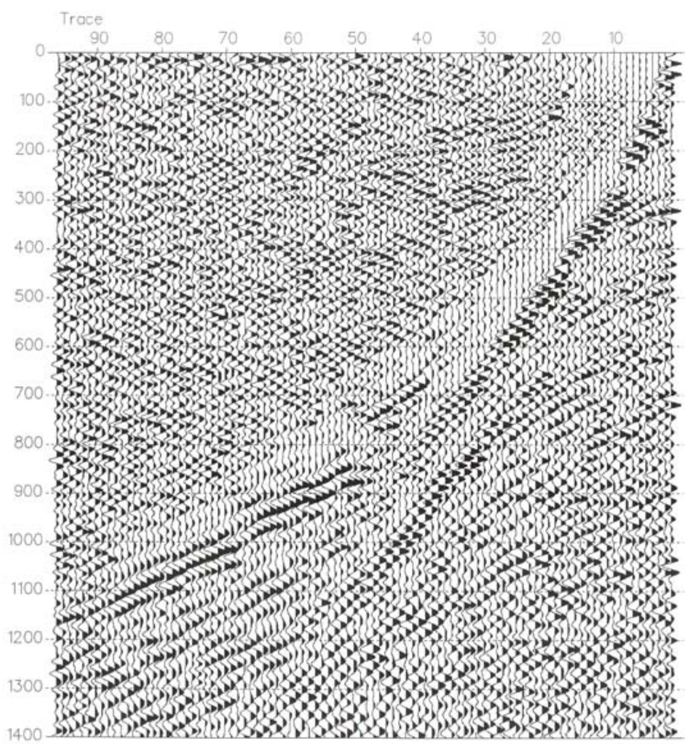

Figure 2b. Example of a processed SH-wave sounding near station TYAR. Time, in milliseconds, is represented on the vertical axis. The trace spacing is 4 meters. Only shallow reflectors can be seen.

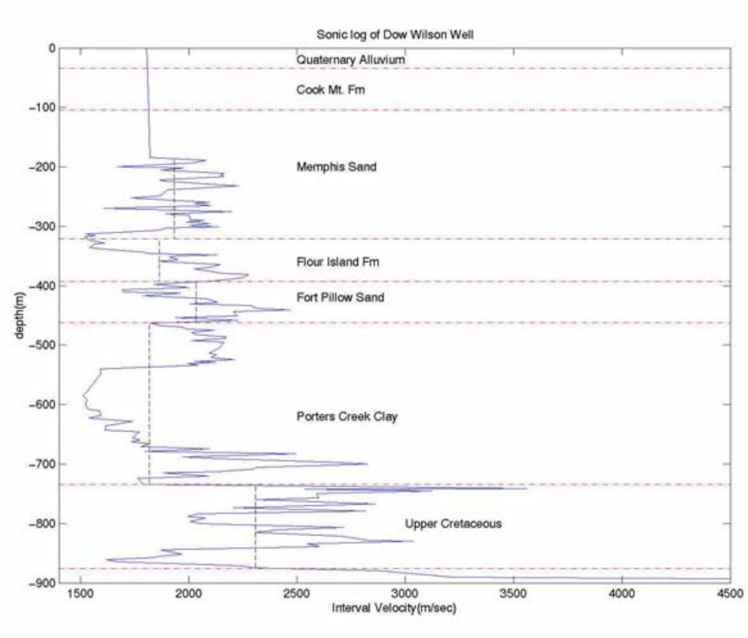

Figure 3. Example of sonic log from the Dow Wilson #1 (AR31) well. Layer boundaries (dashed-dot line) are also shown. Interval velocities shown are digitized from the original record with some errors removed.

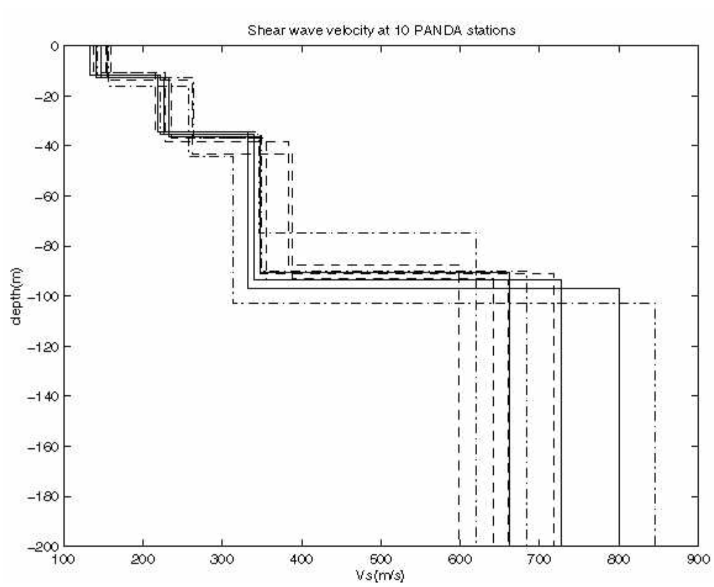

Figure 4. Shallow shear-wave velocity profiles from seismic reflection/refraction lines at various sites showing that shear-wave velocities are slower than the speed of sound in the upper most 100 meters of sediments. The top three interfaces are consistent but not the interval S-wave velocity at deeper depth.

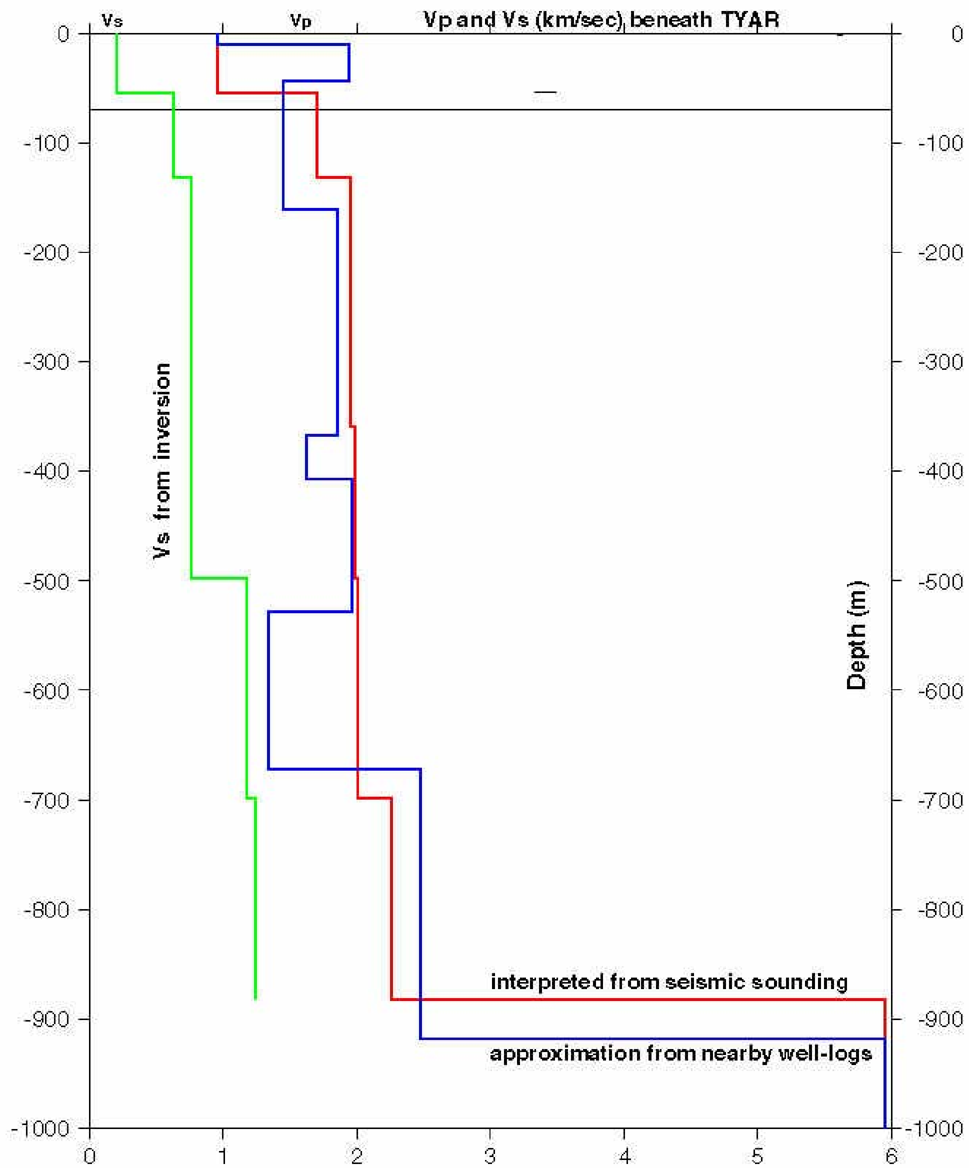

Figure 5. Vp and Vs as a function of depth beneath station TYAR. The red Vp profile is interpreted from a seismic sounding (Figure 2b) and the blue Vp profile is interpolated and extrapolated from nearby well logs. Layer boundaries and interval velocities determined from seismic sounding are consistent with those from nearby well logs within reasonable error ranges. We are currently in the process of re-interpretation of nearby well logs and will try to correlate them with the observed Vp from seismic soundings. The Vp/Vs ratio for each layer can be inverted from a linear inversion using the Vp model, the shallow Vs, and the arrival time difference between the direct S and converted Sp waves (Δt_{S-S_p}) as the *priori* information. Thus, Vs profile (green line) can be determined from the resultant Vp and Vp/Vs information obtained.

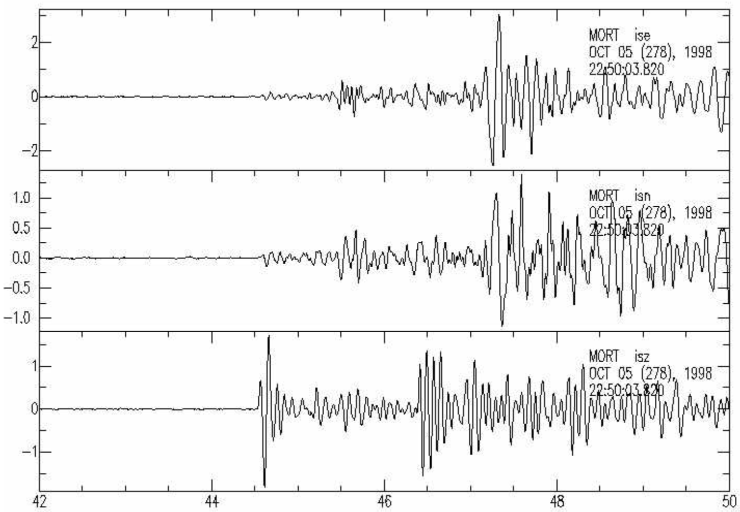

Figure 6. Typical 3-component seismograms at a CERI seismic station (MORT) showing the direct P and the converted Sp waves on the vertical component (bottom) and the direct S and the converted Ps waves on the two horizontal components (top two traces).

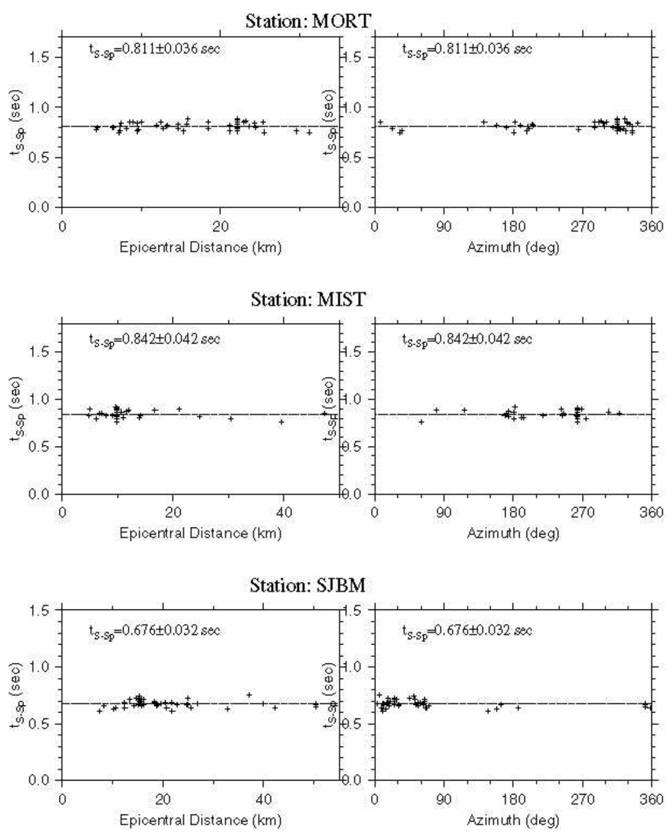

Figure 7. Plots of travel time differences (Δt_{S-S_p}) between the direct S and converted Sp waves versus depth and azimuth of earthquakes from CERI regional seismic network stations showing that Δt_{S-S_p} is a constant for every station but are different between stations.

Non-technical Summary

Traditional seismic reflection and refraction methods have been applied to explore the P- and S-wave velocity model for a few selected sites in the upper Mississippi Embayment. The selected sites are located near CERI seismic stations and adjacent to deep wells with geological and sonic logs. The geological and sonic logs from the deep well provide important constraints for the interpretation of seismic profile and for the validation of the resultant structural model. The S-wave velocity model for the deeper sediments cannot be resolved from the S-wave profile alone using S-wave hammer source. However, the deeper S-wave model can be obtained from a simple linear inversion of Vp/Vs ratio using the P-wave velocity model, the shallow S-wave model, and the observed Δt_{S-S_p} between the direct S and the S-to-P converted waves from the bottom of the sediments as the *priori* information. In the future effort using the MiniVib for S-wave source, we should be able to explore the S-wave velocity model for the entire sediments from seismic profile. A reliable 3-dimensional Vp and Vs model for the sedimentary basin in the upper Mississippi Embayment will become possible if similar research can be done in many more sites.

Reports Published

This is the first year of the project and is supposed to accomplish a few test sites adjacent to logged deep wells to validate the resultant velocity model. Thus, no report has been published so far. Preliminary results of related research have been presented in the SSA and ESSSA meetings. They include:

A single-event relocation of local earthquakes in the NMSZ using a 3-D Vp and Vs crustal velocity model, Chiu, J.M., H. Chen, J. Pujol, S.C. Chiu, and M. Withers, presented in the 97th SSA annual meeting, held at Victoria, Canada, April, 2002, **SRL**, 73(2), 216.

A New earthquake catalog for the New Madrid seismic zone using a preliminary 3-dimensional Vp and Vs structural model, Chiu,J.M., H. Chen, J. Pujol, S.C. Chiu, and M. Withers, presented at the **74th annual ES-SSA meeting** held October 2002 at Boston College, Western, MA.

Preliminary study of Pn velocity and Moho geometry beneath the NMSZ in the central US, Kim, K.H., J.M. Chiu, S.C. Chiu, and M. Withers, presented at the **74th annual ES-SSA meeting** held October 2002 at Boston College, Western, MA.

Data Available

Seismic data from the reflection and refraction profiles are available in SEGY format by contact Ron Street and Edward Woolery at the University of Kentucky (woolery@uky.edu). Local earthquake seismograms in AH format and converted wave information in ASCII format can be obtained by contact Jer-Ming Chiu at the University of Memphis (chiu@ceri.memphis.edu).